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Virtual Prototyping in Power Electronics Using VHDL-AMS Application to the Direct Torque Control Optimisation

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Abstract: This study presents a VHDL-AMS modelling of a complex multi-domain system which is a Direct Torque Control (DTC) of an asynchronous machine and exposes some high-level-simulation results allowing a behavioural study using a virtual way. The detail of both ideal and non-ideal behaviour modelling are presented. The study starts with a comparison between MATLAB and VHDL-AMS functional simulations. Then, the study of the effect of several parameter's variations is exposed; especially the influences of stator resistance, the sampling period and the bit number of A/D converters on the flux and torque behaviour. A VHDL-AMS description presents a good solution to predict system's performances and can provide sensitivity curves giving the evolution of performances versus generic parameter's variation.

Key words: Virtual prototyping, multi-domain system, VHDL-AMS, DTC control system

INTRODUCTION

Because systems are more and more complex, CAD tools must be improved in order to stay efficient with good prediction capabilities. In order to improve time to market, study costs, reusability and reliability of the design process and thus global productivity, we should use a virtual prototyping methodologies. System validation will be done by a global simulation instead of prototype's production.

Designing power electronic systems is based on accurate knowledge of the designers. The procedure allowing the adjustment of performances in order to respect requirements follows a try and test scheme. The design is done step by step, sizing each part but without computer assistance.

In this study, we show how a high level language can be used to model a system including many domains like digital and analogue electronics, power electronics, electrical motor, control, etc. Each domain must be described at the good level of abstraction taking into account the wanted level of results. When the system and its simulation are available, it is possible to drive many studies in a virtual way: comparison of control algorithms, technological choices, etc. At this level, it is possible to talk about Virtual prototyping of a complex system. We show in this study how this approach can be applied to the Direct Torque Control of an asynchronous motor in order to optimise the control algorithm and the embedded hardware. Many types of virtual prototypes can be proposed: ideal ones allowing a global system verification and non-ideal ones providing a virtual study of the influence of several physical parameters.

We first begin this study by giving a short presentation of the DTC control system. A real prototype was realised by implementing the DTC control algorithm in a DSP. To facilitate the system optimisation, virtual prototypes were realised and described with VHDL-AMS.

DTC presentation: Recently, many studies were performed to obtain a variable speed control of induction machines. Among all strategies dealing with this kind of applications, Direct Torque Control (DTC) seems to be especially well-adapted. This technique was developed in the mid 1980, initially applied to the asynchronous machines. It is characterised by the simplicity of its structure, decreasing the parameter sensibility of the machine, rising the dynamic performances and requiring no speed or position sensors. A simple switching logic table allows a flux and torque decoupling. This table is based on a flux and torque hysteresis comparator, a flux detection zone and a machine model. The basic idea of the DTC method consists on the definition of a look up table which specifies the switching pattern, in order to maintain stator flux and electromagnetic torque inside an hysteresis band and close to their references.

The motor control system is defined by both a digital and an analogue parts. Thus, the digital area characterises

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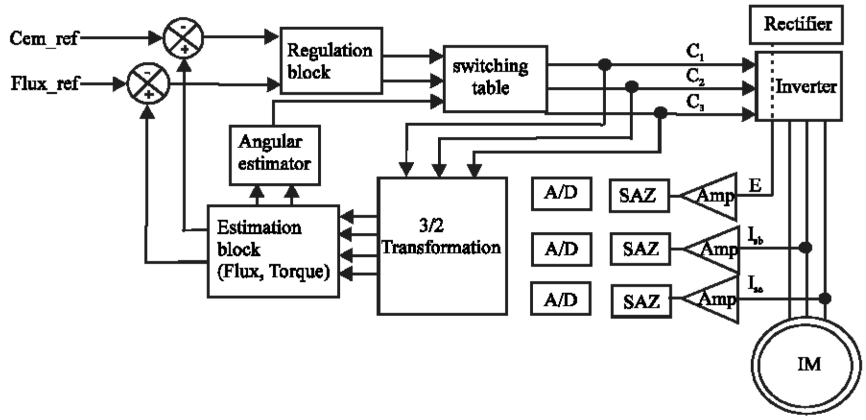


Fig. 1: DTC general structure

the control algorithm, whereas the analogue part contains power inverters, current, voltage and mechanic sensors, filters and Analogue/Digital Converters[1,2].

Figure 1 shows the whole control system of an asynchronous motor. Control variables are directly estimated from stator currents (Isb, Isc), DC voltage E and switching logic control (C1, C2, C3).

DTC implementation: The basic idea of the DTC control is to calculate the instantaneous values of flux and torque in the machine. These values are directly estimated from stator voltages determined with the DC voltage E and the Boolean switching controls C2, C2, C3. Triphased-diphased Concordia transformation is used to compute stator voltage vectors and current vectors on perpendicular (α, β) axis as exposed with the following expressions:

$$V_{s\alpha} = \sqrt{\frac{2}{3}}E \quad (C_1 - 0.5*C_2 - 0.5*C_3) \tag{1}$$

$$V_{s\beta} = \frac{E}{\sqrt{2}}(C_2 - C_3) \tag{2}$$

$$i_{S\alpha}(k)=\sqrt{\frac{3}{2}}.I_{s1}(k) \tag{3}$$

$$i_{S\beta}(k)=\frac{1}{\sqrt{2}}\cdot(I_{s1}(k)+2I_{s2}(k)) \tag{4}$$

The calculation of the constituents of the flux is assured by a system of equations according to:

$$\phi_{S\alpha} = \int\left(V_{S\alpha} - R_s.I_{S\alpha}\right)dt \tag{5}$$

$$\phi_{S\beta} = \int\left(V_{S\beta} - R_s.I_{S\beta}\right)dt \tag{6}$$

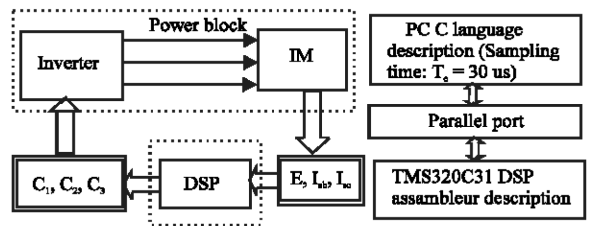


Fig. 2 : DTC Physical Implementation

Where, R_s represents stator resistance.

The estimated field is calculated from the following relations:

$$\phi_{s\_est}(k) = \sqrt{\left(\phi_{S\alpha}(k)\right)^2 + \left(\phi_{S\beta}(k)\right)^2} \tag{7}$$

$$Cem_{est}(k) = P\cdot(\Phi_{S\beta}(k)\cdot I_{S\beta}(k) - \Phi_{S\alpha}(k)\cdot I_{S\alpha}(k)) \tag{8}$$

Where, P is the number of pole pairs.

The DTC control algorithm was implemented on a starter kit board based on the TMS320C31 DSP. The different blocks detailing the realized prototype is shown in Fig. 2. An inverter block receives Boolean switching controls (C1, C2, C3) and drives the asynchronous machine. The measured stator currents (Isb, Isc) and the DC voltage E are injected in the DSP inputs. The implemented algorithm provides on the DSP outputs the switching logic controls.

To optimize the DSP control, we need to change every time the implemented algorithm and to do measures again. To simplify this operation, it is easier to use a virtual way. A formal computation software such as MATLAB_SIMULINK is usually used to validate new concepts of control. When it is a question of real

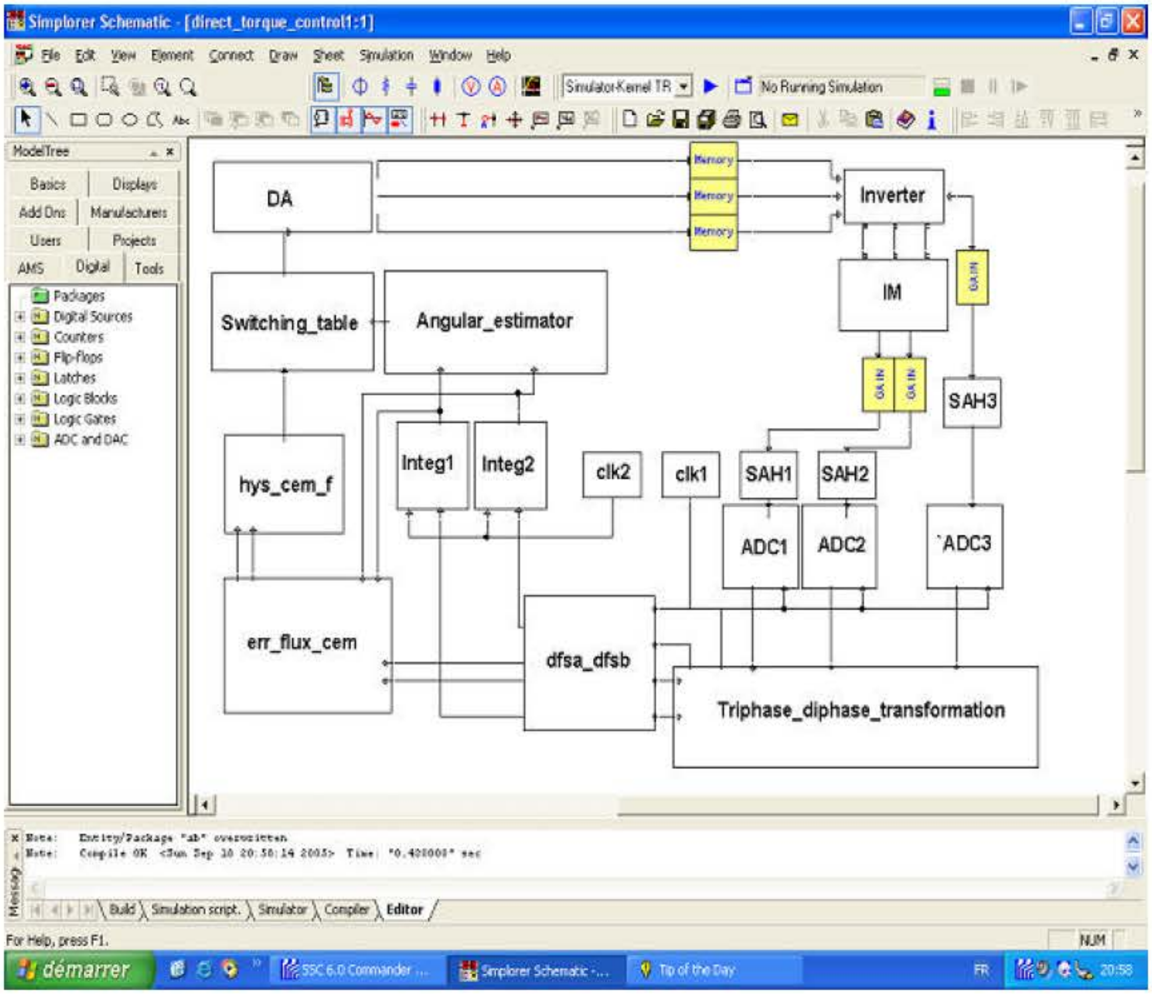


Fig. 3: DTC description in simplorer environment

integration, hardware description languages are more adapted. In the case of a DTC system, it is necessary to do a mixed (analogue and digital) simulation. VHDL-AMS is able to carry out both analogue and digital signals. Furthermore, it provides a suitable simulation environment for a multi-domain system.

VHDL-AMS virtual prototype

Ideal prototype: VHDL-AMS descriptions were developed for each block of the DTC including functional models. The obtained blocks were connected in Simplorer Software environment to obtain a high level description of the DTC (Fig. 3). The exposed blocks include power electronic models (asynchronous machine, load and inverter) and digital and analogue electronic behavioural desciptions (integrator, sensors, A/D converters, etc). It represents a so complex multi-domain system. The whole system is simulated in Simplorer 6.0 Software environment as shown on Fig. 3[3].

On Fig. 4, we compare simulation results obtained with both MATLAB and Simplorer simulators : a circular flux-vector-trajectory is obtained, the flux is regulated around 0.7 Wb and the torque oscillates around 3 Nm. We notice that similar results are obtained with both MATLAB and Simplorer 6.0 simulators.

Non ideal prototype: The ideal prototype for the DTC control is composed of ideal functional models which are not depending on process parameters and just traduce the ideal transfer function for the several blocks constituting the DTC system. In a second step, a non-ideal prototype was developed to simulate the effect of several physical parameters. So we developed new VHDL-AMS descriptions at a lower level of the Top-Down hierarchical design.

To evaluate the efficiency of the developed prototype, we simulated flux and torque evolutions in the time; then we compared the obtained curves to measures

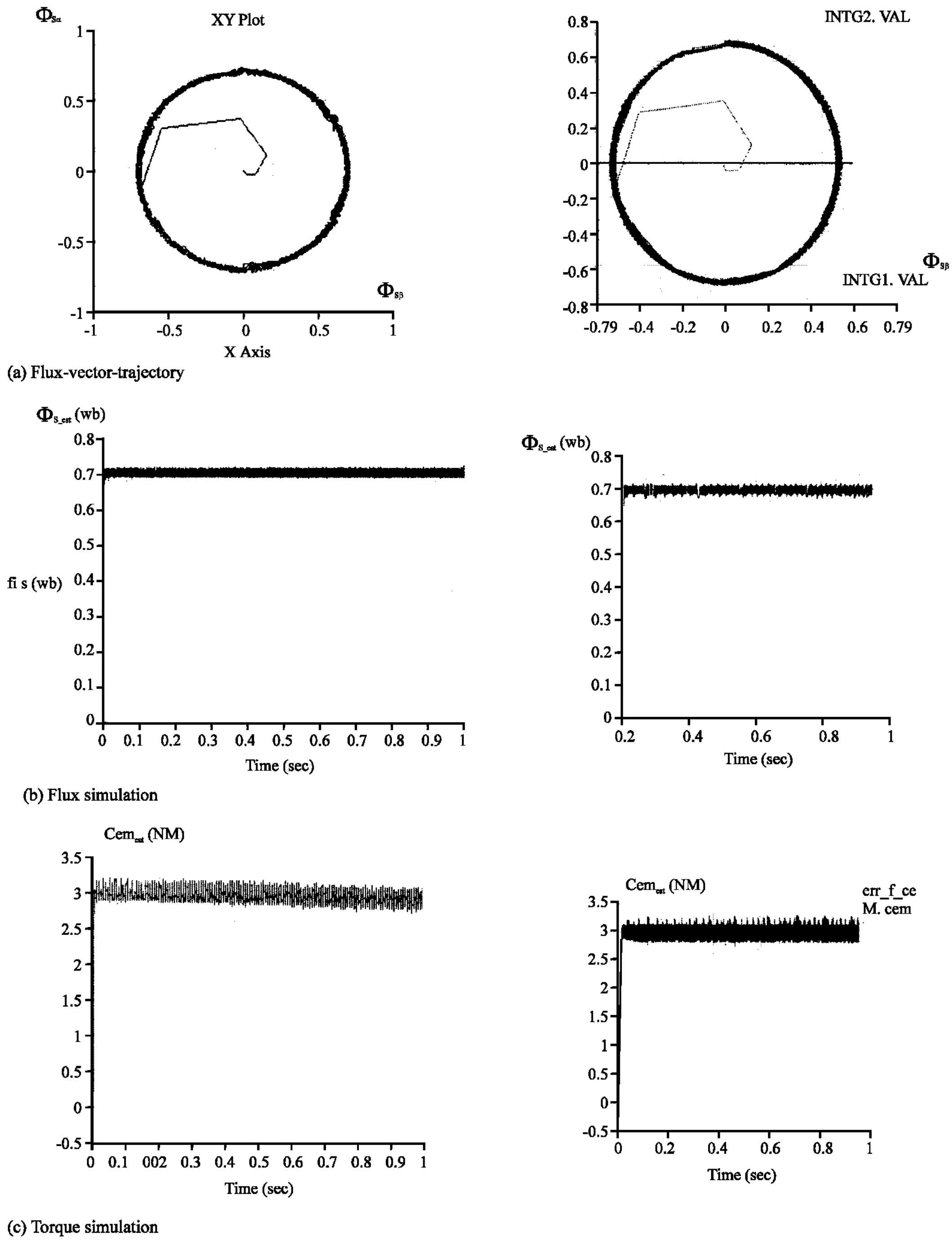


Fig. 4: DTC command system simulation

realized with the real prototype. Figure 5 shows examples of simulation : for the same inputs, both simulated and measured flux and torque are regulated respectively around 0.7 Wb and 3 Nm.

Temperature effect: Several studies made in evidence the sensitivity of induction machine parameters to many factors like temperature, saturation, etc. According to work's of Trigui[4] stator resistance depends on the temperature of the stator windings. The rise in temperature T causes an increase in stator resistance R_s according to the following equation:

$$R_s(T) = R_s(T_0)(1 + \alpha(T-T_0))$$

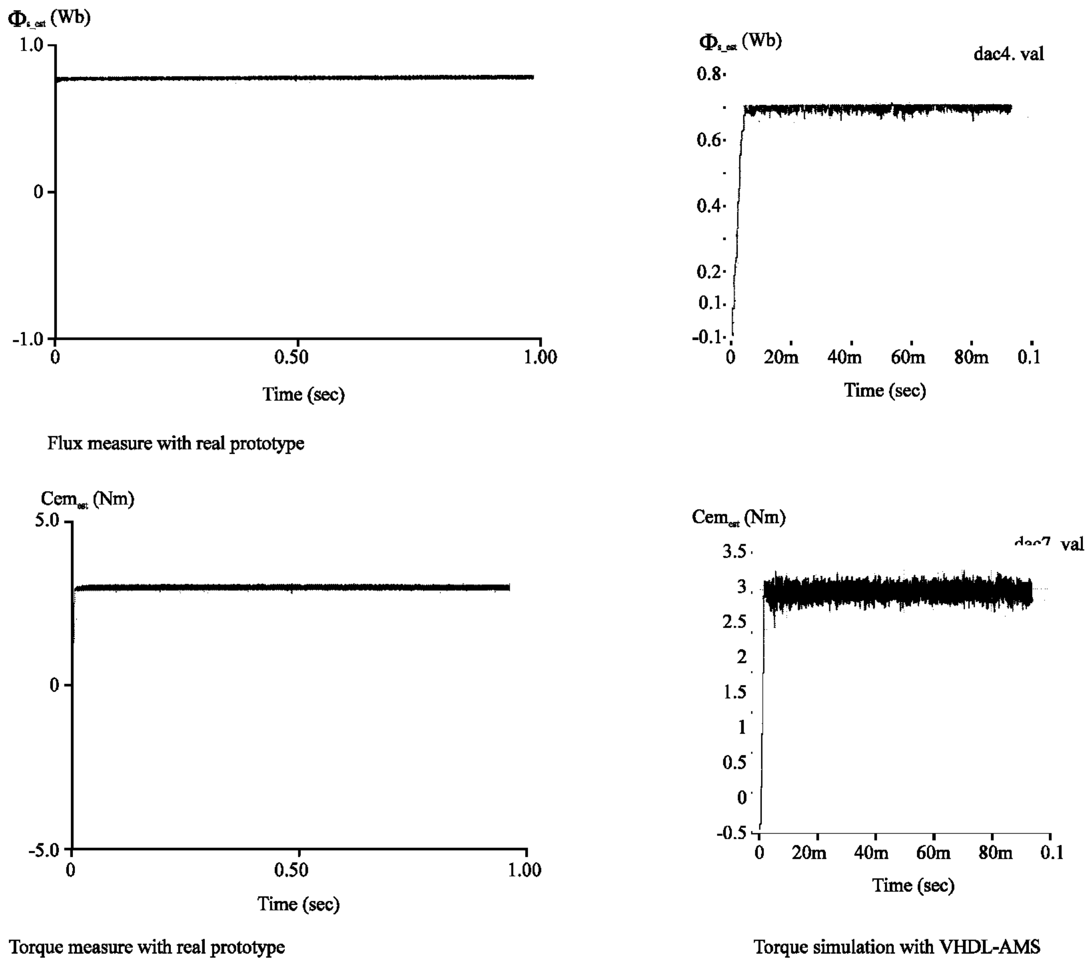


Fig. 5: Flux and torque measurers and simulations

Where, α is the temperature coefficient and T_0 an initial temperature.

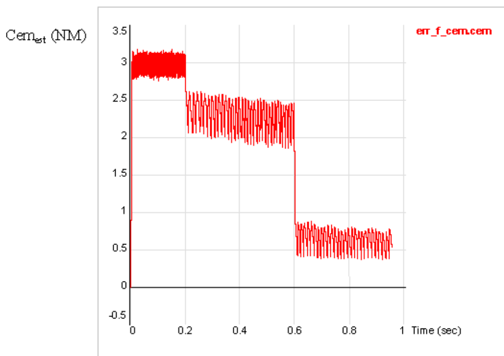
To predict temperature effect with the developed virtual prototype, we introduced this equation in the model of the asynchronous machine. Figure 6 shows the obtained simulation for three temperatures: $T_1 = 20°C$, $T_2 = 40°C$ then $T_3 = 60°C$.

According to Fig. 6, the temperature have a consequent effect on electromagnetic torque, stator flux and flux vector behaviours. This type of simulation using a virtual prototype have two advantages: first, it permits to predict temperature limits giving an acceptable DTC behaviour; second, it is difficult and dangerous to do the same simulations with a real prototype.

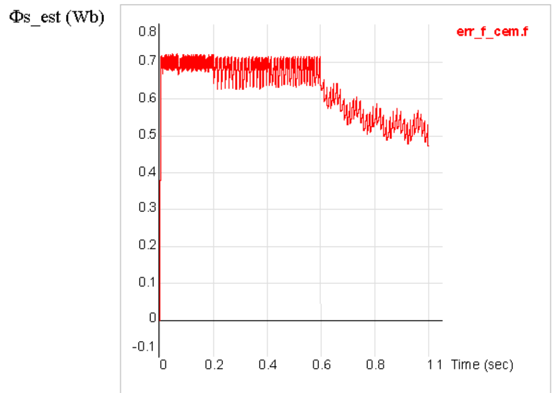
Effect of the hysteresis band: We simulated with our virtual prototype the influence of hysteresis band on the flux and torque behaviour. By increasing the width of this band, Fig. 7 shows the effect on the torque. This type of simulation will be very useful when we want to compute an optimised hysteresis band width. In fact, larger the hysteresis band, less precise but faster the control system.

Effect of the sampling time: The sampling time T_e has an important effect on the DTC control system, especially on torque and flux behaviours. In fact, if sampling time increases, the torque and the flux can leave the hysteresis band width. This effect is simulated and exposed on Fig. 8 for three values: T_e equals 30, 50 and 70 μs. The virtual prototype can easily predict the maximum sampling time that maintains the torque regulated.

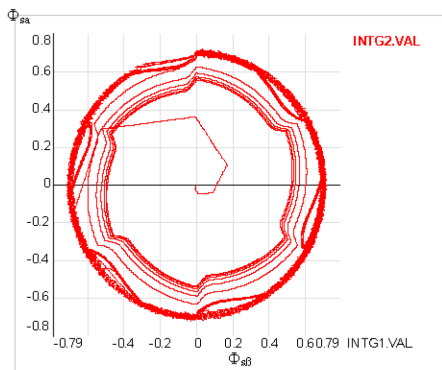
Effect of bit number o the converter: The bit number of the A/D converter (N) has an important effect on the DTC control system, especially on torque and flux behaviours. In fact, torque and flux estimation accuracy depends on the length of the binary data and numerical calculation



Electromagnetic torque



Stator flux



Flux vector

Fig. 6: Temperature effect

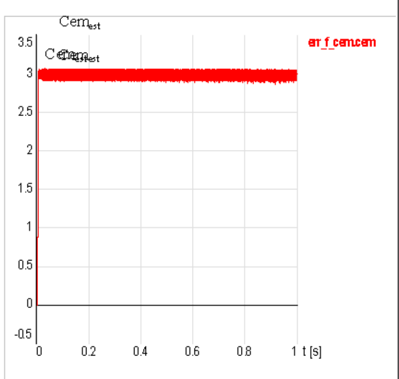
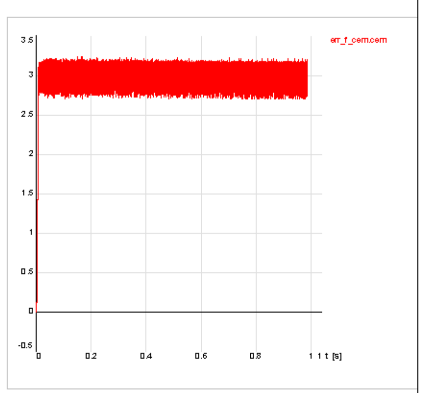
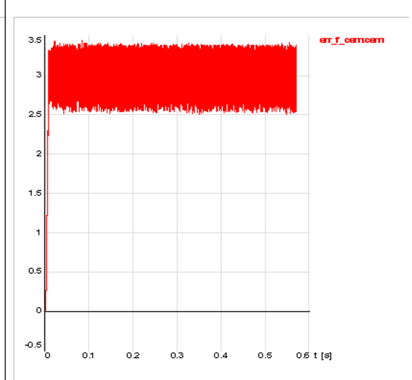
1% nominal value of torque and flux	10% nominal value of torque and flux	15% nominal value of torque and flux
		

Fig. 7: Effect of the hysteresis band width

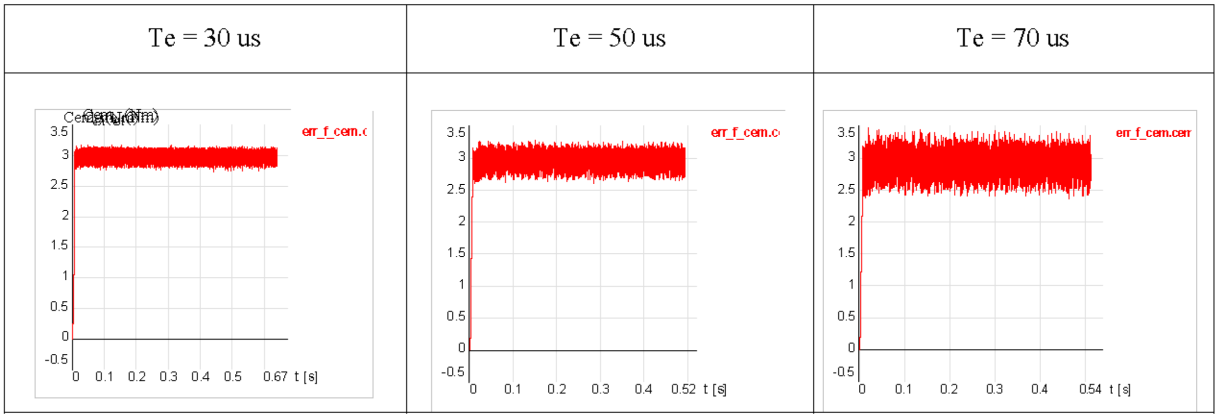
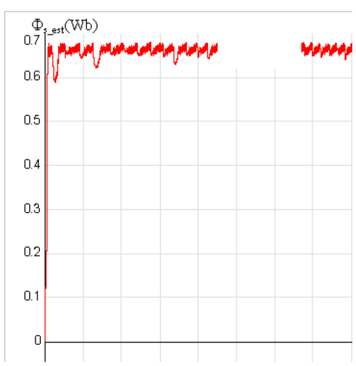
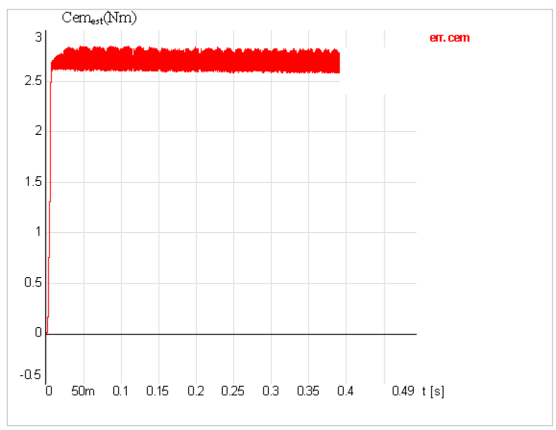


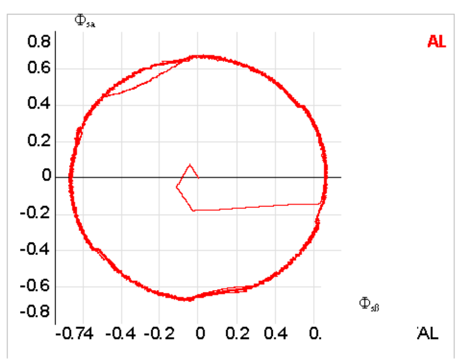
Fig. 8: Effect of the sampling time





Electromagnetic torque

Stator flux



Stator flux vector trajectory

Fig. 9: Effect of converter's bit num

methods. Figure 9 presents torque and flux behaviour simulation obtained with 8 bits A/D converters. Compared to results exposed on Fig. 5 (obtained with 12 bits A/D converters), a degradation of torque and flux regulation is observed. We can see that the torque is controlled around its reference with an hysteresis band correction (3% of nominal value). But stator flux presents many fluctuations and overshoots out of hysteresis band. This effect is more observed on the flux trajectory. This simulation is important to do at a high level design and permits to choice the suitable A/D converter before producing a real prototype.

CONCLUSIONS

This study exposes a high-level description and simulation with VHDL-AMS of a DTC control system. We show how a high level language can be used to model such multi-domain system. At this level, we talk about virtual prototyping making possible the characterisation of the system and the prediction of it's performances. Two types of virtual prototypes are detailed: an ideal one that is used to verify and to optimise the system architecture and a non ideal prototype that allows to study the influence of physical parameters. The obtained results are successfully compared to a real prototype.

REFERENCES

1. Kebbati, Y., 2002. Développement d'une méthodologie de conception matériel à base de modules génériques VHDL/VHDL-AMS en vue d'une intégration de systèmes de commande électriques. Ph.D Thesis, University Louis Pasteur-Strasbourg I.
2. Kebbati, Y., Y.A. Chapuis and F. Braun, 2001. IP modules for motor control FPGA/ASIC integration. The Global System on Chip. Design and CAD Conference (IFIP, VLSI-SOC 2001), France, pp: 385-390.
3. Simplorer 6.0 Software User's Manual.
4. Trigui, R., 1997. Motorisation asynchrone pour véhicules électriques. Modélisation, optimisation et évaluation. Ph.D Thesis, INP, Lorraine.